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(54) Electricity consumption metering with transformer phase angle error compensation

(57) A method or means of metering electricity consumption comprises taking power measurements and compensating said measurements for a phase angle error introduced by transformer means 6 involved in the measuring process. The transformer means 6 may be a current and/or voltage transformer with a predetermined phase angle error characteristic. The meter may use current and voltage measurements i. v to determine real and reactive power values PR(meas), PX(meas) which may be compensated, using compensating means 20 to 28, to provide true real and reactive power values PR, PX. When more than one transformer is involved: respective, average or the difference between phase angle errors may be employed.

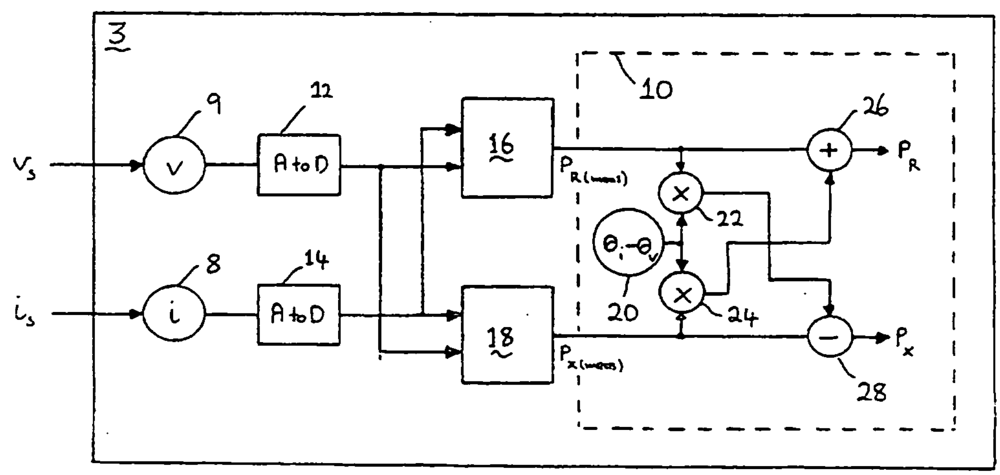

Figure 2.

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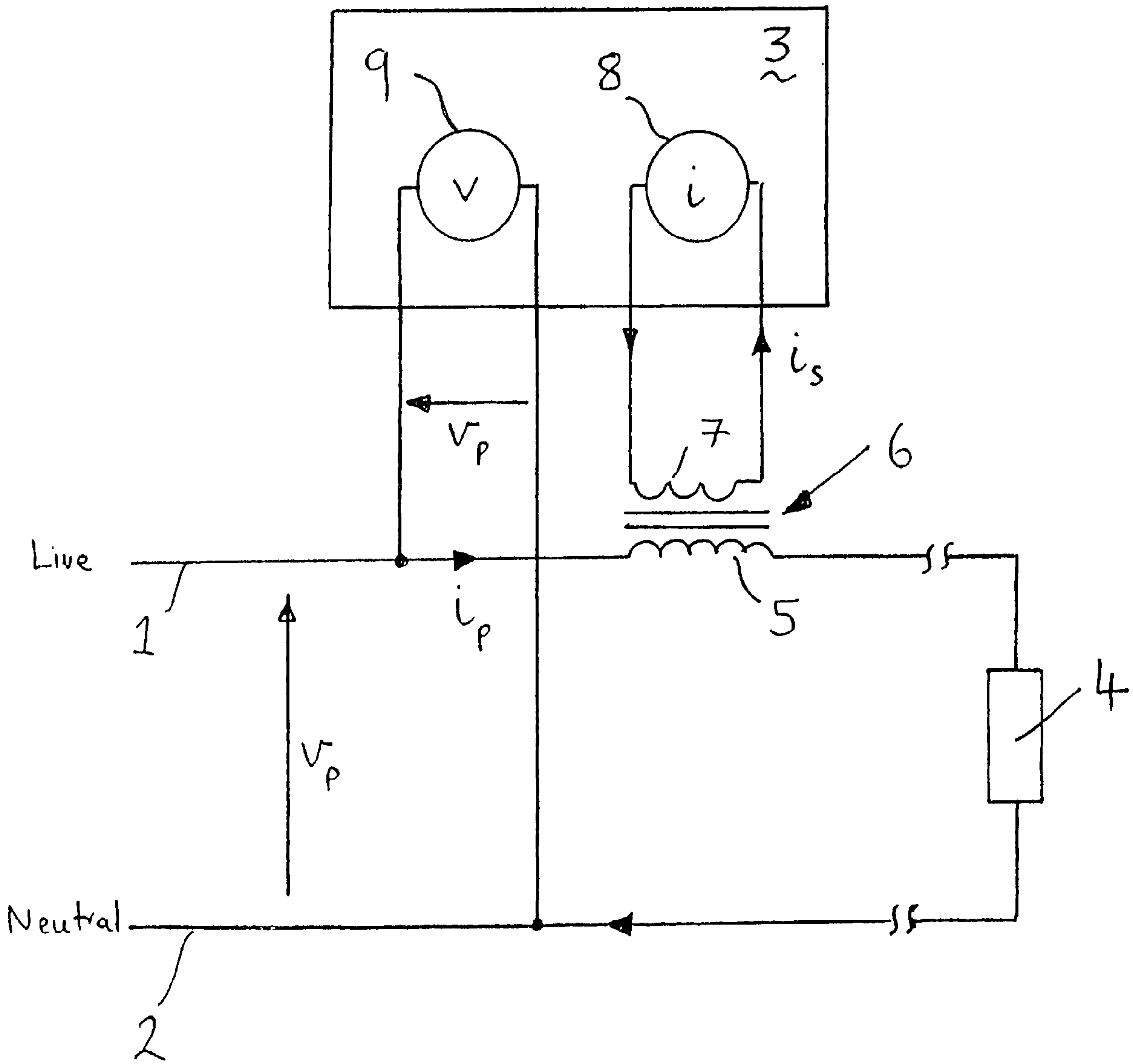

Figure 1(a)

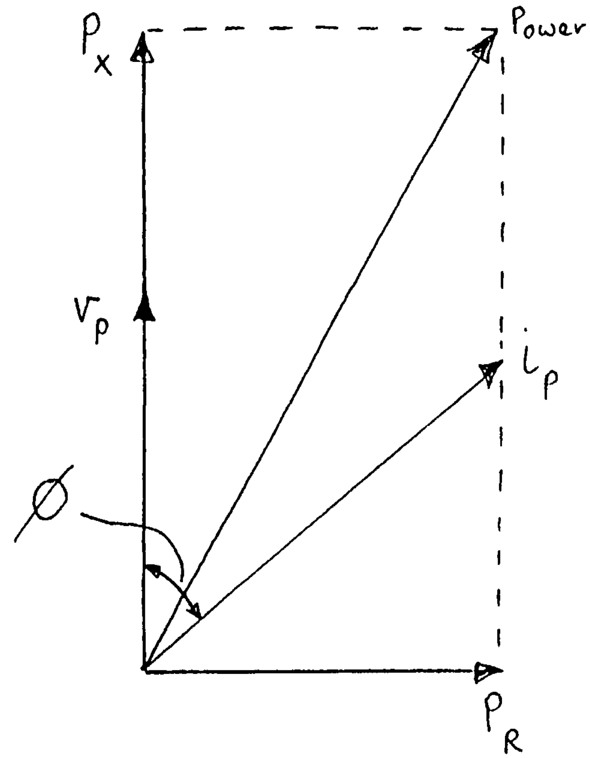

Figure 1(b)

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ELECTRICITY POWER METERING

This invention relates to electricity power consumption metering and in particular to metering which uses a current and/or voltage transformer. More particularly, the invention is concerned with an apparatus for and a method of compensating for phase angle errors associated with the current and/or voltage transformer.

As is known, domestic electricity consumption registering meters include current and voltage sensing elements which are connected directly to the electricity supply lines such that the load current passes through the current sensing element and the supply voltage is connected across the voltage sensing element. The meter determines the power consumed from the product of the voltage and current and integrates this value over a period of time to obtain a measure of the energy consumed. Such meters are found to work effectively for currents up to a 100 amps and for supply voltages of 240 volts rms.

For applications in which the maximum current exceeds 100 amps, for example in commercial premises such as Offices or Supermarkets, it is known to measure the current indirectly using a current transformer. The current transformer which is separate from the electricity meter is connected such that its primary winding is connected in the live supply line and the secondary winding of the transformer is connected to the current sensing element of the meter. Such an arrangement enables measurements of high currents without the need for the current sensing element of the meter to be capable of

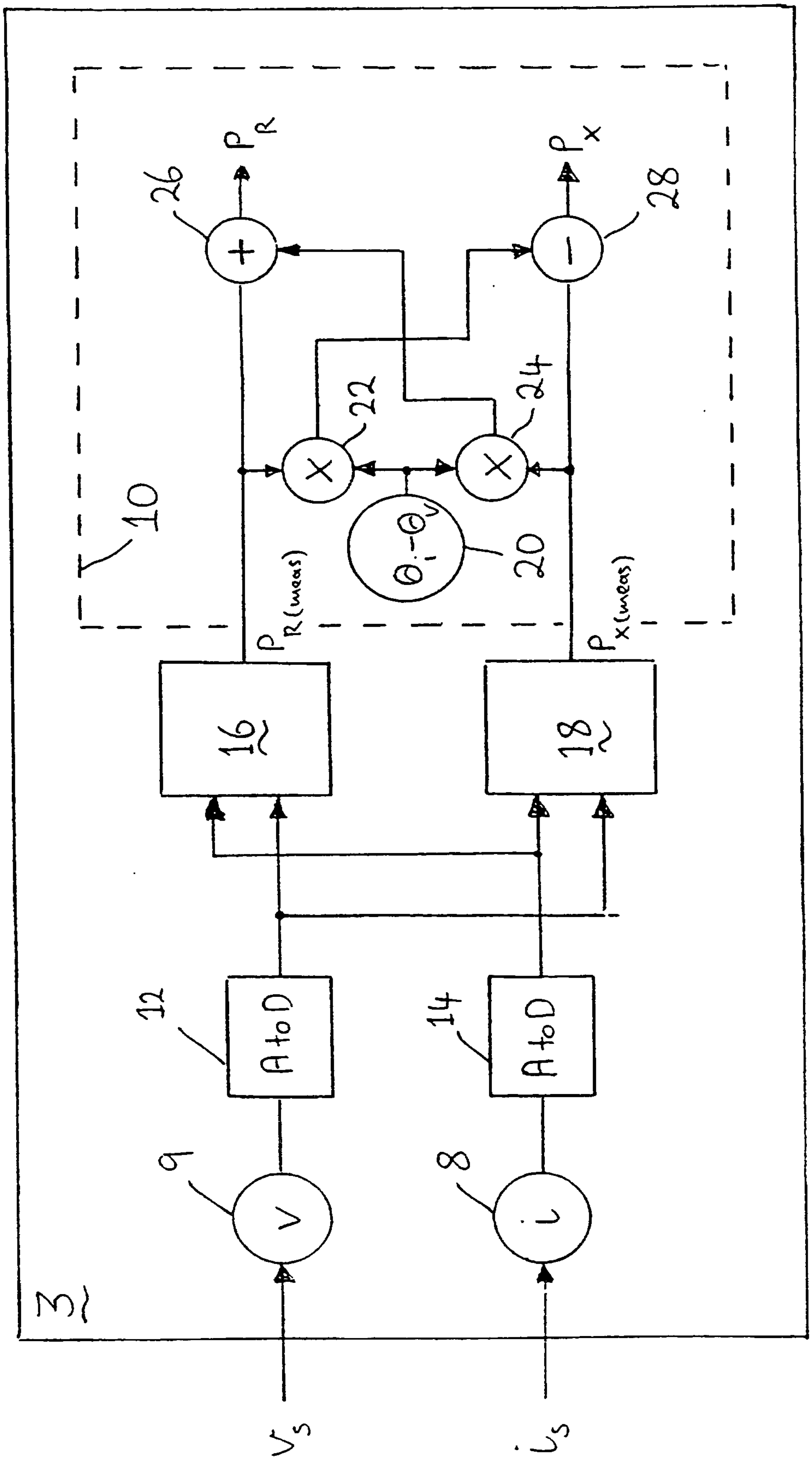

Figure 2.

withstanding high currents.

Furthermore for applications in which the supply voltage exceeds 240 volts, such as industrial applications in which the supply voltage is typically 11,000 volts, a voltage transformer may be used in addition to a current transformer. The voltage transformer which is again separate from the electricity meter has its primary winding connected between the supply lines and its secondary winding connected to the voltage sensing element of the meter.

Whilst current and/or voltage transformers provide a reasonably accurate determination of energy consumption they do have two sources of error which can lead to inaccuracies in the measurement of power by the meter. The first is the transformer turns ratio error. This occurs when the actual ratio of the number of turns in the primary winding to the secondary winding differs from the rated transformer turns ratio. This error depends upon the physical geometry of the particular transformer and as such the actual transformer turns ratio can be measured prior to installation of the transformer. As a result it is possible to correct for transformer turns ratio errors by multiplying the measured value of current and/or voltage by a compensation factor which is programmed into the electricity meter during installation.

A second source of error is phase angle error, sometimes referred to as phase angle displacement, which results in the waveform at the secondary winding not being exactly in phase with the waveform at the primary winding. A particular problem in compensating for phase angle displacement is that this error depends upon the magnitude

of the parameter (current or voltage) being measured and the system phase angle. As a result any error in the measured power is dependent upon the instantaneous power and hence the power factor of the system and unlike transformer ratio errors phase angle errors cannot readily be compensated for, and therefore no effort has been made to compensate for such errors.

The present invention addresses the technical problem of correcting for phase angle errors of current and/or voltage transformers in electrical power measurement.

According to the present invention an electricity consumption meter for use with a current and/or voltage transformer having a known phase angle error characteristic, said electricity meter comprises:

real power measuring means for determining the measured real power;

reactive power measuring means for determining the measured reactive power; and

compensation means which are operative to determine the true real power in dependence on the measured reactive power, the phase angle error characteristic and the measured real power.

By using the present invention it is possible to obtain a value for the true real power from measured values of the real and reactive power and the phase angle error characteristic.

Preferably the compensation means determines the true real power by multiplying the measured reactive power by the phase angle characteristic and adding the product to the measured real power.

Conveniently the phase angle error characteristic for the transformer can be measured prior to installation of the transformer and comprises a value which is representative of the average phase angle error. Alternatively the compensation means includes a memory containing values of phase angle errors for given currents or voltages.

In a preferred embodiment the compensation means is further operative to calculate the true reactive power in dependence on the measured real power, the phase angle error characteristic and the measured reactive power. Such an arrangement enables the true reactive power to also be determined from the measured real and measured reactive power. Preferably the compensation means determines the true reactive power by multiplying the measured real power by the phase angle error characteristic and subtracting the product from the measured reactive power.

When both a current and voltage transformer are used which have respective phase angle error characteristics the phase angle error characteristic above is dependent upon the respective phase angle error characteristics. In a preferred arrangement the phase angle error characteristic comprises the difference between the respective phase angle error characteristics.

According to a second aspect of the invention a method for compensating for errors in an electricity power measuring system of a type which use a current and/or voltage transformer which has a known phase angle error characteristic said method comprises:

measuring the real power;

measuring the reactive power;

determining the true real power in dependence the measured reactive power, the phase angle error characteristic; and the measured real power.

Conveniently the true real power is determined by:

multiplying the measured reactive power by the phase angle error characteristic; and

adding the product to the measured real power.

In a preferred embodiment the method further comprises determining the true reactive power in dependence on the measured real power, the phase angle error characteristic and the measured reactive power. Conveniently the true reactive power is determined by multiplying the measured real power by the phase angle error characteristic and subtracting the product from the measured reactive power.

When both a current and voltage transformer are used which have respective phase angle error characteristics the phase angle error characteristic used in the method of the invention is dependent on the respective phase angle error characteristics.

The present invention finds particular application with the privatisation of the electricity supply in the UK which requires more accurate metering. As a result of privatisation consumers have the right to purchase electricity from any supplier and charging will be based on consumption during half-hourly intervals. For settlement purposes between the Regional electricity companies, electricity generating companies and/or consumers it will be necessary to meter electricity consumption in half-hourly intervals. Any errors in the measured power as a consequence of transformer phase angle error could be financially significant and as a result more accurate metering is required. For example in the UK under the pooling and settlement agreement code of practice five the overall accuracy of electricity measurement has been stipulated as ±1½% at unity power factor, and ±2½% at half power factor for measurements of the real power . These figures take account of not only any errors due to the current and/or voltage transformer but also any errors in the meter itself. The present invention provides both an apparatus and method that meets this requirement.

One embodiment of the invention will now be described by way of reference to the accompanying drawings in which:

Figures 1(a) and (b) are schematic diagrams illustrating the parameters associated with measuring electrical power using a current and/or voltage transformer; and

Figure 2 is an electricity consumption meter incorporating apparatus in accordance with the present invention.

Referring to Figure 1 an electricity supply comprises live and neutral supply lines 1, 2 respectively. An electricity consumption meter 3 is provided to measure the electrical energy supplied to a consumer's load 4. The primary winding 5 of a current transformer 6 is connected in series with the live supply line 1, and the secondary winding 7 of the transformer 6 is connected to the current sensing element 8 of the meter 3. The meter 3 also includes a voltage sensing element 9 for measuring the voltage v_p between the live and neutral supply lines 1, 2. The true apparent power is the product of the current i_p and the voltage v_p. Depending upon the type of load 4, that is whether it is resistive or reactive, the voltage v_p and current i_p may not be in phase and will have a phase angle ϕ between them.

As will be appreciated from the Figure 1b the true apparent power P has a real component P_R and a reactive component P_X. The real, sometimes termed active, power P_R represents the energy consumed as a result of resistive loading whilst the reactive power P_x results from reactive loading. Whilst the reactive loading P_x does not provide any useful power in the load 4 it does however cause current flow in the distribution cables 1, 2 which results in heat loss and as a result its value is usually measured. From Figure 1b it will be appreciated that the:

true real power $P_R = v_p i_p \cos\phi$ and the (1)

true reactive power $P_x = v_p i_p \sin\phi$ (2)

where $\cos\phi$ = the system power factor (PF)

For an ideal current transformer 6, that is one having no phase angle errors, such that the

current flowing in the secondary winding is in phase with the current i_p and which has a turns ratio of 1:n (secondary:primary) the current flowing in the secondary i_s winding, which is the current measured by the current sensor 8 of the meter 3 is given by:

$$i_s = \frac{i_p}{n} \tag{3}$$

and hence true real power $P_R = v_p\, i_s n \cos\phi$ (4)

true reactive power $P_X = v_p\, i_s n \sin\phi$ (5)

However a real transformer will have a phase angle error θ_i which is defined as being positive when the signal appearing at the secondary winding leads the signal at the primary winding. As a result the current and hence power measured by the meter will be subject to error such that the:

$$\text{measured real power} = v_p i_s n \cos(\phi + \theta_i) \tag{6}$$

$$= v_p i_s n \cos\phi_i \cos\theta_i - v_p i_s n \sin\phi \sin\theta_i \tag{7}$$

that is the:

measured real power = (true real power) $\cos\theta_i$ - (true reactive power) $\sin\theta_i$ (8)

According to International Electromechanical Commission (IEC) 185, a class 0.5 current transformer is required to have a phase angle error of less than 1½° (90 minutes) and hence:

$1 \geq \cos\theta_i > 0.9996$ so that $\cos\theta_i$ can be approximated to be unity. As a result the

measured real power = true real power - (true reactive power) sin θ_i (9)

For small values of θ_i, sin $\theta_i \approx$ angle θ_i in radian, and rearranging (9) the

true real power = measured real power + (true reactive power) θ_i (10)

for θ_i in radians.

The true reactive power is an unknown quantity which is also subject to error. However when the measured reactive power is large, and thus making a significant contribution to the true real power, it is also within a few percent of its true value. When the measured reactive power is small it is subject to a large error, however it is multiplied by θ_i which is a small value. As a consequence it is practicable to approximate the real reactive power as being equal to the measured reactive power and hence:

True real power = measured real power + (measured reactive power) θ_i (11)

It will be appreciated from the above that the true real power can be determined from the measured real and measured reactive powers provided the phase angle error θ_i is known. The value of θ_i can be determined from measurements of the transformer prior to installation. Similarly it can be shown:

true reactive power = measured reactive power - (measured real power) θ_i (12)

Further it can be shown if a voltage transformer is also included whose phase angle

error is θ_v then the:

true real power = measured real power + (measured reactive power) $(\theta_i - \theta_v)$ (13)

and

true reactive power = measured reactive power - (measured reactive power) $(\theta_i - \theta_v)$ (14)

where θ_i and θ_v are specified in radians.

It will be appreciated from the above that both the true real power and true reactive power can be determined from the measured real power, measured reactive power and the phase angle error.

Referring to Figure 2 there is shown an electricity consumption meter 3 which incorporates apparatus 10 in accordance with the present invention. The electricity meter 3 which is of a known design is operated with both a current and voltage transformer (not shown). The meter 3 comprises a current sensor 8 and voltage sensor 9 which are connected to the secondary windings of the current and voltage transformer. The outputs of the sensors 8 and 9 are converted to a stream of digital data values by means of respective analogue to digital converter (A-to-D) 12 and 14. The digital data values are multiplied and accumulated using respective accumulators 16, 18 to produce values for the measured real power $P_{R(meas)}$ and measured reactive power $P_{x(meas)}$.

The meter 3 also incorporates apparatus 10 in accordance with the present invention which compensates for the phase angle errors θ_i and θ_v associated with the current and voltage transformers. The apparatus 10 comprises a memory 20 which produces a value

for $(\theta_i . \theta_v)$. The memory 20 may contain a single average value of $(\theta_i - \theta_v)$ or a look-up table containing several values depending on the magnitude of the instantaneous current and/or voltage. The value or values of $(\theta_i - \theta_v)$ are measured prior to installation of the transformers and written to the memory 20.

The value of $(\theta_i - \theta_v)$, which is measured in radians, is applied to a first input of two respective multiplier circuits 22 and 24. The first multiplier 22 multiplies the measured real power $P_{R(meas)}$ by $(\theta_i - \theta_v)$ whilst the second multiplier 24 multiplies the measured reactive power $P_{X(meas)}$ by $(\theta_i - \theta_v)$. The output from the second multiplier 24 is added to the measured real power $P_{R(meas)}$ using an adding circuit 26 to produce a value which is representative of the true real power P_R in accordance with equation (12). The output from the first multiplier 22 is combined with the measured reactive power $P_{X(meas)}$ by means of a subtracting circuit 28 to produce a value which is representative of the true reactive power P_X in accordance with equation (13).

It is found that using the apparatus 10 of the present invention with a known meter which is accurate to 1% of reading an overall accuracy of better than 1½% can be achieved. Such accuracy is a substantial advance on the prior art arrangement which can be subject to additional errors of 4% at half power factor for measurement of the real power depending on the magnitude of the phase angle error.

It will be appreciated by those skilled in the art that modification can be made to the embodiment described which remain within the scope of the present invention. For example whilst in the embodiment illustrated the apparatus 10 comprises discrete digital

circuitry the invention could be implemented using software or analogue circuitry. Although the memory 20 contains one or more values, for $(\theta_i - \theta_v)$ it is also envisaged to have an arrangement which calculates values of $(\theta_i - \theta_v)$ in dependence on the magnitude of current and/or voltage being measured. For example other values of $(\theta_i - \theta_v)$ can be determined by interpolating between the known values. Further it will be appreciated that the measurement of the real $P_{R(meas)}$ and reactive power $P_{X(meas)}$ can be performed using other known methods such as for example a slipping sampling technique. Although in the embodiment described the true real and true reactive power were determined using discrete mathematical steps as defined in equations 10 to 13, it is also envisaged that these values could be determined using other mathematics and signal processing techniques such as for example a Fourier analysis.

CLAIMS

1. An electricity consumption meter for use with a current and/or voltage transformer, the transformer having a known phase angle error characteristic said meter comprising:

real power measuring means for determining the measured real power;

reactive power measuring means for determining the measured reactive power; and

compensation means which are operative to determine the true real power in dependence on the measured reactive power, the phase angle error characteristic and the measured real power.

2. An electricity consumption meter, according to Claim 1, wherein the compensation means determines the true real power by multiplying the measured reactive power by the phase angle characteristic and adding the product to the measured real power.

3. An electricity consumption meter, according to Claim 1 or Claim 2, wherein the compensation means is further operative to determine the true reactive power in dependence on the measured real power, the phase angle error characteristic and the measured reactive power.

4. An electricity consumption meter, according to Claim 3, wherein the compensation means determines the true reactive power by multiplying the measured real power by the phase angle error characteristic and subtracting the product from the measured reactive power.

5. An electricity consumption meter, according to any preceding claim, wherein when both a current and voltage transformer are used which have respective phase angle error characteristics said phase angle error characteristic is dependent on the respective phase angle characteristics.

6. An electricity consumption meter, according to Claim 5, wherein the phase angle error characteristic comprises the difference between the respective phase angle error characteristics.

7. An electricity consumption meter, according to any preceding claim, wherein the phase angle error characteristic comprises a value representative of the average phase angle error.

8. An electricity consumption meter, according to any one of Claims 1 to 6, wherein the compensation means includes a memory containing values for the phase angle errors for given currents and/or voltages.

9. An electricity consumption meter, according to any preceding claim, in which the real power measuring means comprises a voltage sensor for measuring

instantaneous voltage, a current sensor for measuring instantaneous current and combining means for combining the outputs from the current and voltage sensors to determine the measured real power and measured reactive power.

10. An electricity consumption meter substantially as described, or illustrated by way of reference to Figure 2 of the accompanying drawings.

11. A method for compensating for errors in an electricity power measuring system of a type which uses a current and/or voltage transformer which has a known phase angle error characteristic, the method comprising:

measuring the real power;

measuring the reactive power;

determining the true real power in dependence on the measured reactive power, the phase angle error characteristic and the measured real power.

12. A method, according to Claim 11, comprising determining the true real power by:

multiplying the measured reactive power by the phase angle error characteristic; and

adding the product to the measured real power.

13. A method, according to Claim 11 or Claim 12, and further comprising determining the true reactive power in dependence on the measured real power phase angle error characteristic and the measured reactive power

14. A method, according to Claim 13, comprising determining the true reactive power by multiplying the measured real power by the phase angle error characteristic and subtracting the product from the measured reactive power.

15. A method, according to any one of Claims 11 to 14, in which both a current and voltage transformer are used which have respective phase angle error characteristics and wherein said phase angle error characteristic is dependent upon the respective phase angle error characteristics.

16. A method, according to Claim 15, wherein the phase angle error characteristic comprises the difference between the respective phase angle error characteristics.

17. A method, according to any one of Claims 11 to 16, wherein the phase angle error characteristic comprises a value representative of the average phase angle error.

18. A method for compensating for errors in an electricity power measuring system of a type which was a current and/or voltage transformer which has a known phase angle error characteristic, the method substantially as described by any one of equation 11, 12, 13 or 14.

The Patent Office

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Application No:	GB 9623542.9	**Examiner:**	John Watt
Claims searched:	1 - 18	**Date of search:**	19 December 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1U (UR1120, UR2100, UR2106, UR2107, UR21133)

Int Cl (Ed.6): G01R 11/20, 21/00, 21/06, 21/07, 21/133

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2031166 A	(C. G. S.) see lines 29-38 of page 1	1 and 11
X	EP 0466453 A2	(POLYMETERS) see whole document	1 and 11 at least
A	EP 0403330 A1	(SCHLUMBERGER) see line 51 of col.1 to line 10 of col.2	1 and 11
A	US 4887028	(LANDIS & GYR METERING) see lines 45 - 62 of col.1 and lines 24 - 47 of col. 3	1 and 11

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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